Orbit Response Matrix Commissioning at RHIC

APEX Workshop 2010
October 18, 2010

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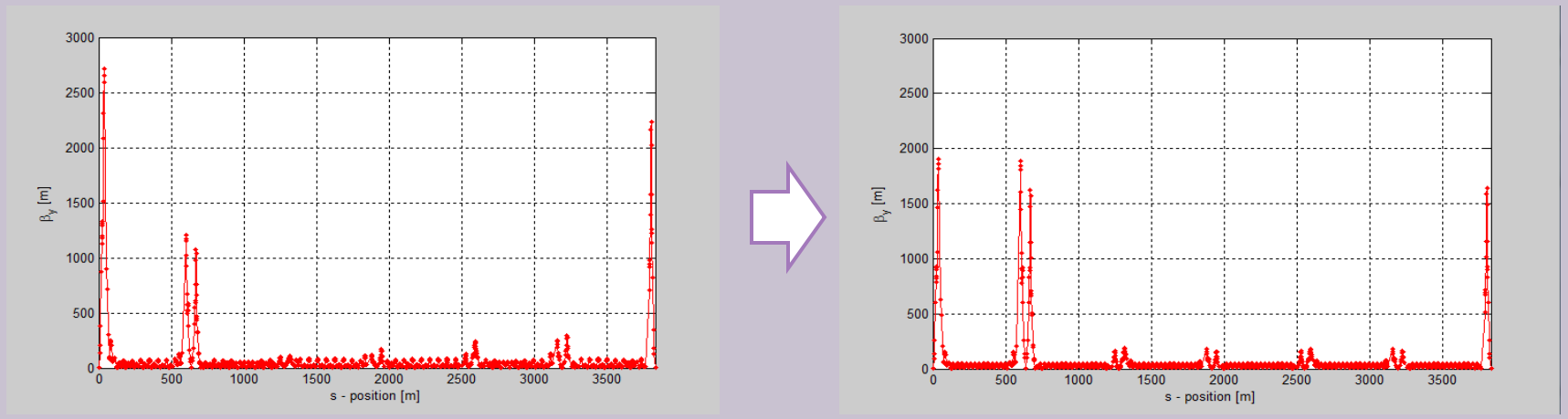
BNL-CAD

The Purpose of ORM

- **Find and correct errors in storage ring linear optics**
- Compare a measured orbit response matrix to the model
  - Fit parameters in model are adjusted until model matches measured
  - Find BPM and corrector offsets
  - Find quadrupole strength errors and rolls
  - Restore lattice symmetry



Generating the Data

- Start with list of correctors – calculate size of kick to get maximum response in arcs
- Measure baseline orbit, change corrector in each ring, measure new orbit
- Measure Horizontal and Vertical planes separate, but Blue and Yellow rings together
- Takes 2 hours to complete both planes
- Need to save machine lattice files (design)

```
1 #!/bin/tcsh -f
2 ######################################################################
3 ./orm.pl bi1-th3 yo1-th2 0.00774390321712892 0.00861864028163694
4 ./orm.pl bi1-th5 yo1-th4 0.0159724845810633 0.0239260469060398
5 ./orm.pl bi1-th7 yo1-th6 0.0206332325894713 0.0222427719537938
6 ./orm.pl bi1-th9 yo1-th8 0.0203054161524584 0.0208503309285232
7 ./orm.pl bi1-th11 yo1-th10 0.020621230686861 0.0204661661572301
8 ./orm.pl bi1-th13 yo1-th12 0.0203797693516555 0.0205108463882891
9 ./orm.pl bi1-th15 yo1-th14 0.020664509404488 0.0204290837953759
10 ./orm.pl bi1-th17 yo1-th16 0.0203516200625966 0.0205356343550386
11 ./orm.pl bi1-th19 yo1-th18 0.0206769848740387 0.0204098634496941
12 ./orm.pl bi1-th21 yo1-th20 0.020355751729253 0.020563924729105
13 ./orm.pl bo2-th20 yi2-th19 0.0200861129826991 0.020565359714291
14 ./orm.pl bo2-th18 yi2-th17 0.0208603996964928 0.0204966451915098
15 ./orm.pl bo2-th16 yi2-th15 0.0201407520140505 0.0205249906768779
16 ./orm.pl bo2-th14 yi2-th13 0.0207715567914651 0.0205376697879686
```

```
1 bi1-th3 -0.000101461143544
2 yo1-th2 8.42926695838e-05
3 Blue bi1-th3 0 baseline Wed Jan  6 20:03:43 EST 2010
4 Wed_Jan__6_20:03:17_2010.sdds
5 Wed_Jan__6_20:03:34_2010.sdds
6 Wed_Jan__6_20:03:36_2010.sdds
7 Wed_Jan__6_20:03:37_2010.sdds
8 Yellow yo1-th2 0 baseline Wed Jan  6 20:03:43 EST 2010
9 Wed_Jan__6_20:03:18_2010.sdds
10 Wed_Jan__6_20:03:34_2010.sdds
11 Wed_Jan__6_20:03:36_2010.sdds
12 Wed_Jan__6_20:03:37_2010.sdds
13 setting bi1-th3 to -9.37172403268711e-05, yo1-th2 to 9.2911309865437e-05 (real)
14 Blue bi1-th3 7.74390321712892e-06  Wed Jan  6 20:03:56 EST 2010
15 Wed_Jan__6_20:03:37_2010.sdds
16 Wed_Jan__6_20:03:48_2010.sdds
17 Wed_Jan__6_20:03:49_2010.sdds
18 Wed_Jan__6_20:03:51_2010.sdds
19 Yellow yo1-th2 8.61864028163694e-06  Wed Jan  6 20:03:56 EST 2010
20 Wed_Jan__6_20:03:37_2010.sdds
21 Wed_Jan__6_20:03:48_2010.sdds
22 Wed_Jan__6_20:03:49_2010.sdds
23 Wed_Jan__6_20:03:51_2010.sdds
24 setting bi1-th3 to -0.000101461143544, yo1-th2 to 8.42926695838e-05 (real)
25 bi1-th5 3.11075502691e-05
26 yo1-th4 2.89973452571e-05
27 Blue bi1-th5 0 baseline Wed Jan  6 20:04:11 EST 2010
28 Wed_Jan__6_20:03:51_2010.sdds
29 Wed_Jan__6_20:04:02_2010.sdds
```

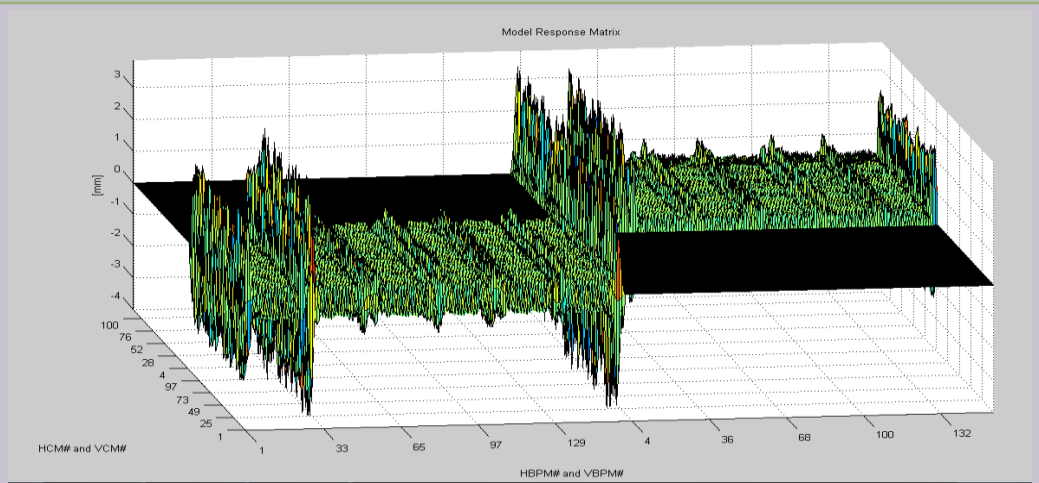
Assembling the Data

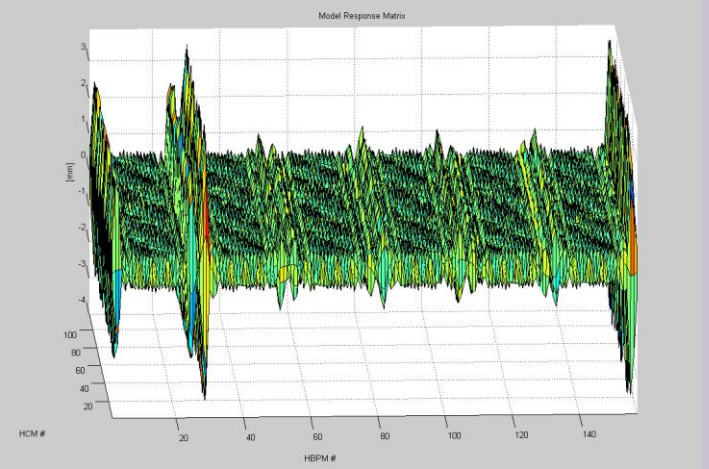
Blue-Au102-store-design.sxf

```
//  SXF version 1.0
ring sequence
{
  "g6-markx"
    marker {
      tag = g6-markx
      at =  0.00000000000e+00
    };
  "g6-bx"
    monitor {
      tag = g6-bx
      at =  7.99313400000e+00
    };
  eldxmp06
    multipole {
      tag = eldxmp06
      at =  9.80000000000e+00
    };
  "g6-dhx"
    sbend {
      tag = g6-dhx
      at =  1.16501096878e+01
      l =  3.70021937559e+00
      body = {
        kl = [ -1.88579569387e-02 ]
      }
      body.dev = {
        kl = [ 0.0  0.00000000000e+00  5.16443668467e-02 ]
      }
      entry.dev = {
        kl = [ 0.0 -0.00000000000e+00 -7.33998067962e-04 ]
      }
      exit.dev = {
        kl = [ 0.0 -0.00000000000e+00 -1.66735363586e-03 ]
      }
    };
```

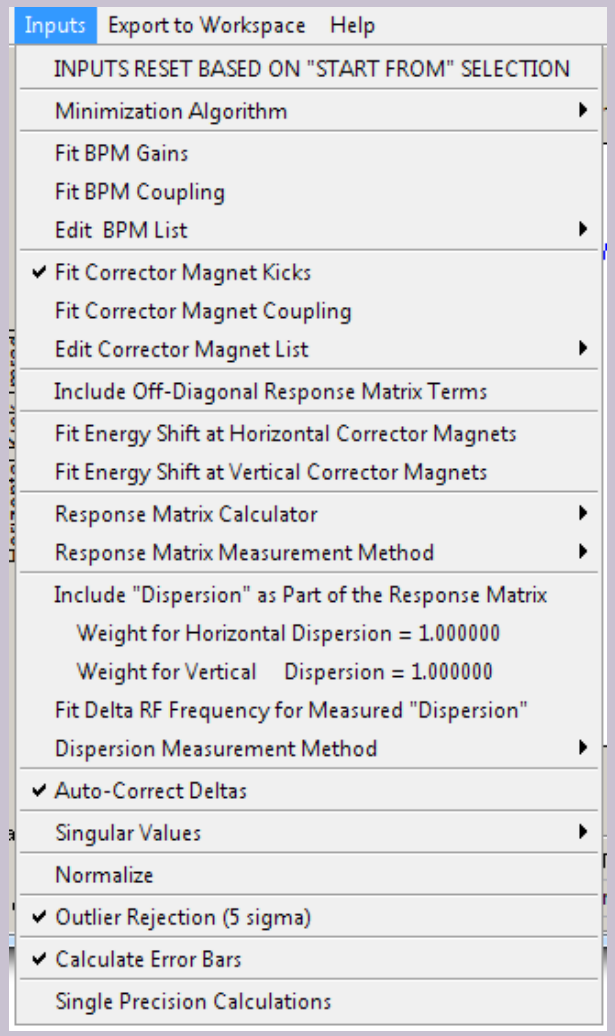
```
% Element definitions:

g6markx = marker('g6markx', 'IdentityPass');
DRIFT1 = drift('DRIFT1', 7.993134, 'DriftPass');
g6bxh = hmonitor('g6bxh', 'IdentityPass');
g6bx = monitor('g6bx', 'IdentityPass');
g6bxv = vmonitor('g6bxv', 'IdentityPass');
DRIFT2 = drift('DRIFT2', 1.806866, 'DriftPass');
g6dhx = sbend('g6dhx', 3.70021937559e+00, -1.88579569387e-02, 0, 0, 0, 'BndMPoleSymplect
erdxmp06 = quadrupole('ELDX', 1e-10, -961487.901076, 'StrMPoleSymplectic4Pass');
DRIFT3 = drift('DRIFT3', 7.006893798955, 'DriftPass');
bo6dh0 = sbend('bo6dh0', 3.58896623069e+00, 1.51804205016e-02, 0, 0, 0, 'BndMPoleSymplec
DRIFT4 = drift('DRIFT4', 0.927703761354999, 'DriftPass');
bo6b1h = hmonitor('bo6b1h', 'IdentityPass');
bo6b1 = monitor('bo6b1', 'IdentityPass');
bo6b1v = vmonitor('bo6b1v', 'IdentityPass');
DRIFT5 = drift('DRIFT5', 0.336944800000001, 'DriftPass');
bo6qd1 = quadrupole('bo6qd1', 1.44000000000e+00, -0.0575190064271528, 'StrMPoleSymplectic
DRIFT6 = drift('DRIFT6', 1.182428, 'DriftPass');
bo6th2 = corrector('bo6th2',0, [0.00000000e+00 0.00000000e+00], 'CorrectorPass');
DRIFT7 = drift('DRIFT7', 0.494203500000001, 'DriftPass');
bo6qf2 = quadrupole('bo6qf2', 3.39163300000e+00, 0.0560097755243566, 'StrMPoleSymplectic
DRIFT8 = drift('DRIFT8', 1.3709615, 'DriftPass');
bo6qs3 = quadrupole('bo6qs3', 1.00000000000e-06, 0, 'StrMPoleSymplectic4Pass');
```

Machine list and archived files -> Matlab lattice file and text response matrix

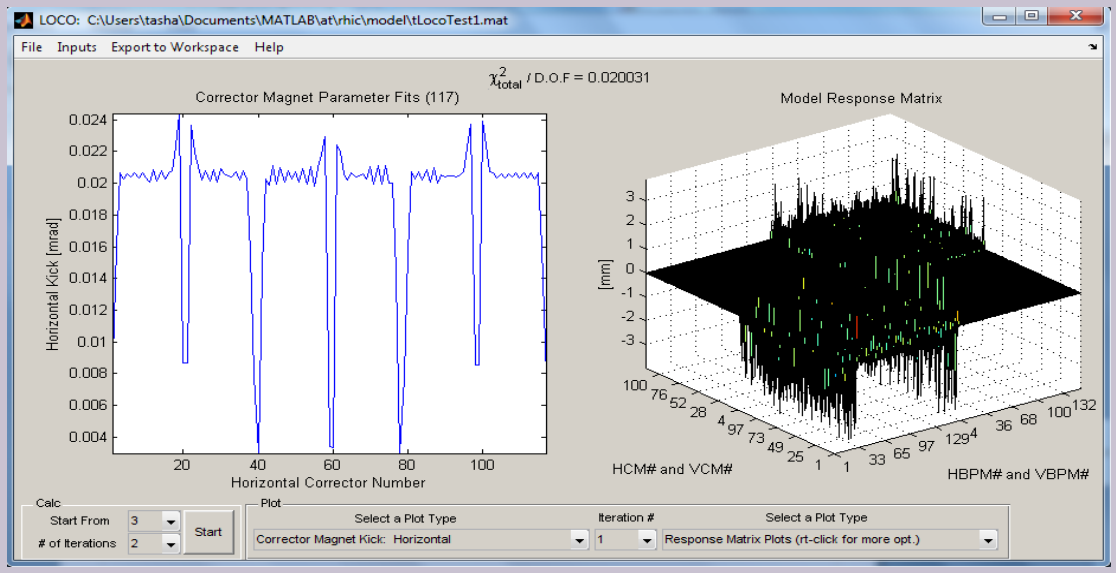




LOCO

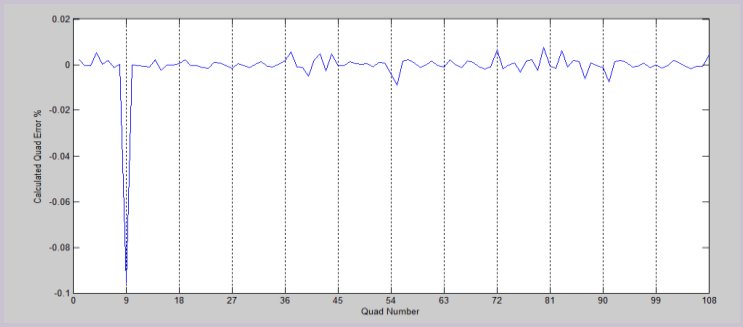


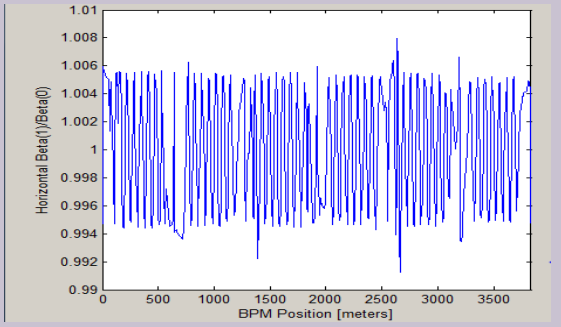
- Uses Matlab Accelerator Toolbox tracking code (developed at SSRL)
- LOCO first written in Fortran, re-written in Matlab to make use of easy matrix calculations and AT
  - used extensively at lightsources
- Gradient search, least squares minimization using SVD to match model to measurement

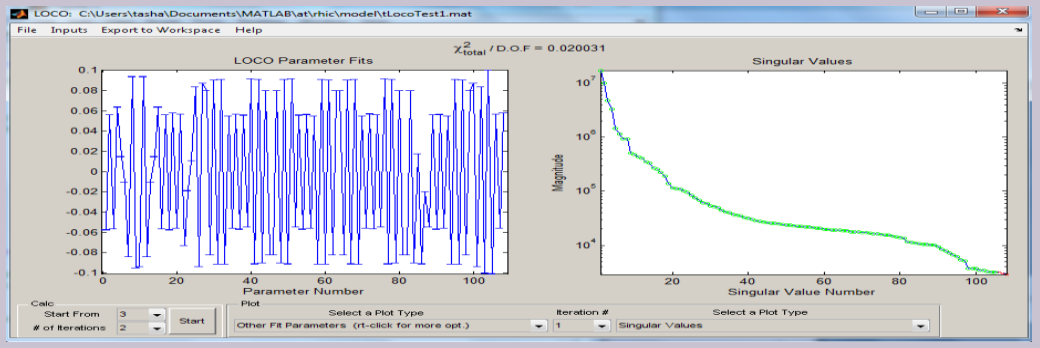


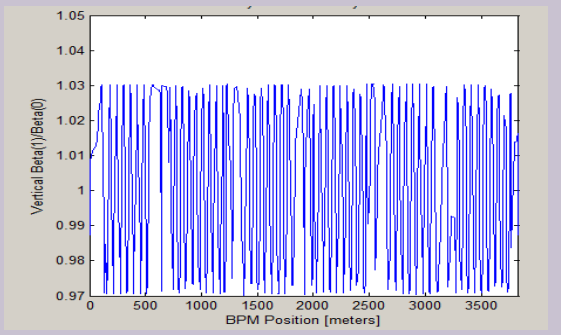
LOCO Simple Test

- Question: can LOCO find known errors in this lattice?
- Added 1 error at bo6-qd9 – 1%
  3% vertical beta beat, < 1% horizontal
- Fit to quads 1-9 in each sector
- Start:
  χ^2/dof = 0.1
  First iteration
  χ^2/dof = 0.02







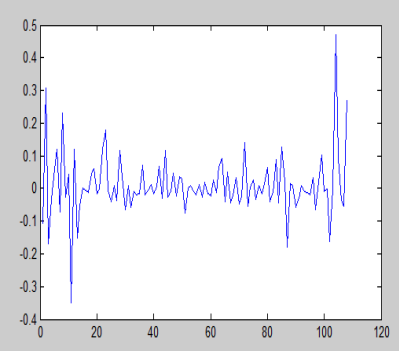


LOCO Simple Test 2

Question: what about an error in the low-β* triplet?

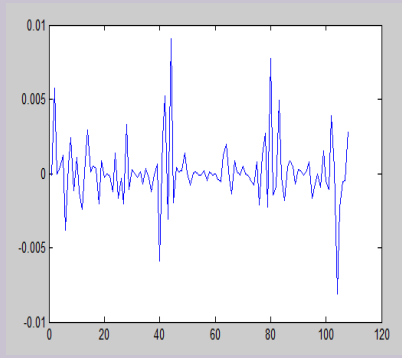
Added 1 error at bo6-qf2 – 0.5%

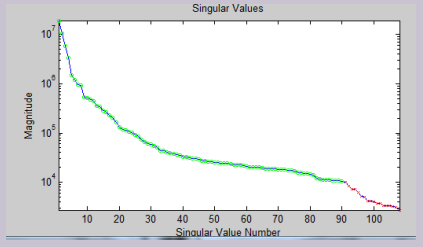
- Fit to quads 1-9 in each sector
- Start:
  χ^2/dof = 798.9
  First iteration
  χ^2/dof = 3056
  Second iteration
  χ^2/dof = 5189



Added 1 error at bo6-qf2 – 0.1%

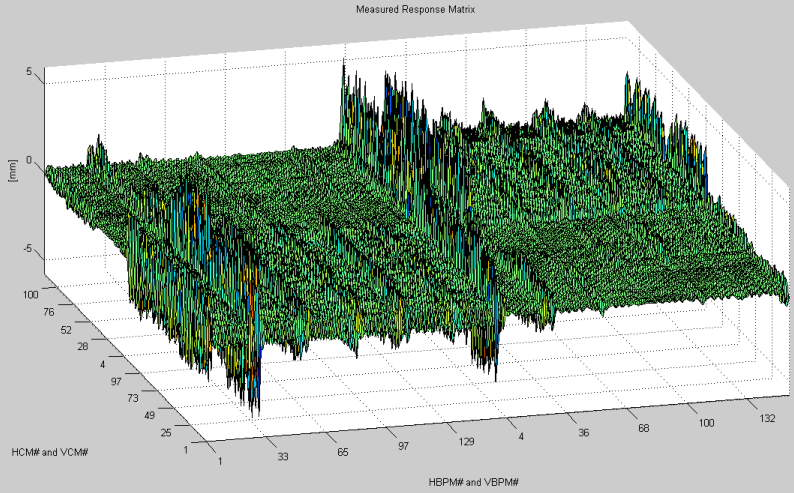
- 10% vertical beta beat,
  20% horizontal
- Start:
  χ^2/dof = 5.1
  First iteration
  χ^2/dof = 0.168
  Second iteration
  χ^2/dof = 0.022



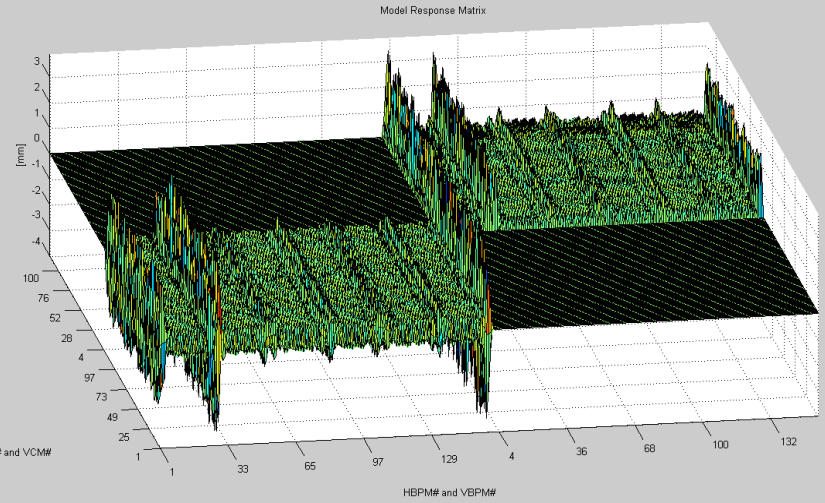


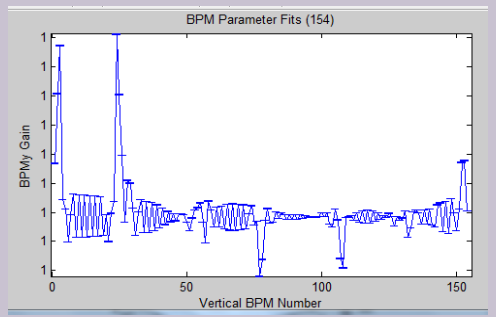
LOCO cannot resolve errors between triplet quads
– phase advance is too small
For a good fit, need to have both HBPM and VBPM between each quad

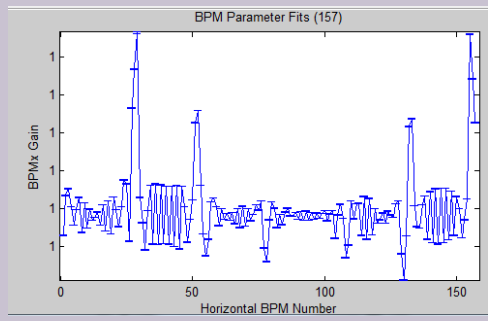
January 2010 Au102 Store, Blue Ring

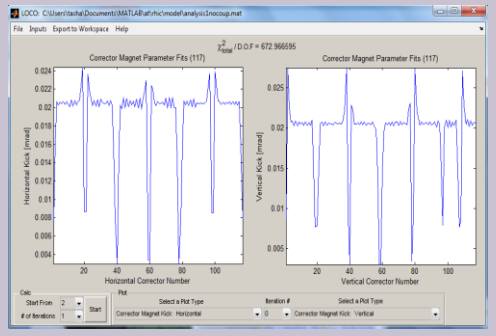


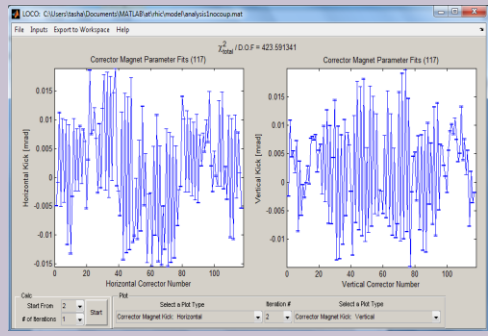
Measured ORM and Model

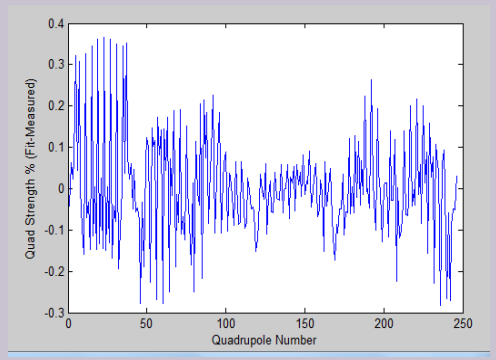


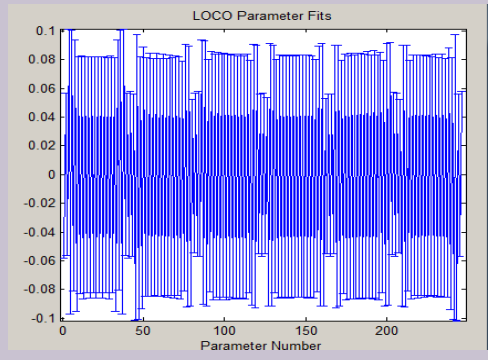












Selecting all options and pressing ‘Start’ doesn’t really work…

Next:

- **Lots** more simulation
  - Find which quads are best to fit and where degeneracies are
  - Random gradient errors in quads as BPM noise changes – determine how much orbit averaging is needed
  - Have Loco solve for random errors in BPMs and corrector kicks
  - Try finding errors in the arc quads
  - Start looking at the coupled matrix
- Should take data with every major lattice change
- Compare responses at store before and after beta squeeze

- See T. Satogata and J. Niedziela C-A/AP Note # 267 February 2007
  Simulations of RHIC Orbit Response Analysis using LOCO